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EVALUATION OF TELEMETRY SYSTEMS CHARACTERISTICS AND STANDARDS

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FOREWORD

This document summarizes the findings of a program designed to standardize missile and space telemetry systems within the Air Force. The effort described herein was conducted under ESD Task 5931.14 of Project 5931.

The data for this report was acquired and categorized by the Electronic Systems Division and the MITRE Corporation. Recommended revisions to the IRIG Telemetry Standards and suggested studies were the results of a coordinated evaluation. A detailed treatment of the evaluation is presented in ESD-TDR-64-155 entitled "A Study of Non-Standard Telemetry System Characteristics". The collection of data was begun in June 1963 and is continuing. However, it is felt that subsequent data will not materially alter the evaluation.

This report represents the efforts of the Directorate of Aerospace Instrumentation, Electronic Systems Division, and The MITRE Corporation.

ABSTRACT

Summarized in this report are the findings of a program entitled "Telemetry Systems Standardization." The primary objective of the program is to standardize on a minimum number of telemetry systems which will meet present and future Air Force requirements. This report represents the initial step toward this goal by providing an insight into the usage of present telemetry systems through the categorization of the characteristics of telemetry systems. Included also is a summarization of the recommendations and suggested studies arising out of a thorough evaluation of the data and IRIG Telemetry Standards reported separately in ESD-TDR-64-155, "A Study of Non-Standard Telemetry System Characteristics."

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

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LIST OF ABBREVIATIONS

AFETR	Air Force Eastern Test Range
AFFTC	Air Force Flight Test Center
AFMTC	Air Force Missile Test Center
AFSC	Air Force Systems Command
AFSWC	Air Force Special Weapons Center
AIA	Aerospace Industries Association
AM	Amplitude Modulation
APGC	Air Proving Ground Center
ASD	Aeronautical Systems Division
BSD	Ballistic Systems Division
cps	Cycles per second
DDR&E	Department of Defense Research and Engineering
DOD	Department of Defense
DSB	Double Side Band
ESD	Electronic Systems Division
FM	Frequency Modulation
IF	Intermediate Frequency
IRIG	Inter Range Instrumentation Group
kc	Kilocycles (1000 cycles per second)
mc	Megacycles (1, 000, 000 cycles per second)
NASA	National Aeronautics and Space Administration
NRD	National Range Division
PACM	Pulse Amplitude Code Modulation
PAM	Pulse Amplitude Modulation
PCM	Pulse Code Modulation
PDM	Pulse Duration Modulation
PPM	Pulse Position Modulation
PRD	Program Requirements Document
RF	Radio Frequency
SCO	Subcarrier Oscillator
SPO	System Program Office
SSB	Single Side Band
SSD	Space Systems Division
TDR	Technical Documentary Report
TWG	Telemetry Working Group
UHF	Ultra High Frequency
USAF	United States Air Force
VHF	Very High Frequency
WSMR	White Sands Missile Range

1.0 INTRODUCTION

1.1 Purpose of Document

This report briefly describes the origin of the Telemetry Standardization Program, its objectives, and progress.

It is hoped that this publication will result in a better understanding of the work and problems faced by this program, and that a mutual exchange of ideas will enable all civilian and military organizations to join in a cooperative effort to standardize telemetry to the maximum extent possible.

1.2 Objectives of the Program

The objectives of this program are to save resources and time and to standardize on a minimum number of telemetry systems which will meet Air Force requirements. To accomplish this, existing systems as well as range equipment will have to be optimized, which in turn will require an up-dating of the standards. Cooperation and coordination is necessary between IRIG/TWG, NRD, ESD, and User SPO's to minimize incompatibilities, to assure that contractors are aware of the latest telemetry standards, and to assure that proposed deviations from these standards are in fact essential to program requirements and cannot be met by a standard system. As requirements change, up-dating and/or replacing of standard systems will become necessary. This program was organized to accomplish these objectives

at substantial savings, by minimizing hardware, development, and operating costs. Cooperation throughout the telemetry community will assure that this program will meet future objectives and requirements.

1.3 History of the Program

On 10 May 1961 AFMTC indicated in a letter to Hqs USAF, DDR&E, and AFSC that ground telemetry systems and ground equipment need to be standardized if effective range support was to be expected in support of Mercury, Advent, Dynasoar and other programs. This letter further pointed out that non-standard equipment should not be developed without prior proof that standard IRIG telemetry equipment cannot meet the requirements, and that technical as well as economic justification be given for the proposed systems.

On 27 June 1961, Dr. Harold Brown of DDR&E sent a letter to the Assistant Secretaries of the Air Force, Army and Navy stating that DOD should request adherence to the IRIG Standards to the maximum practical extent, and that the Range Commanders be responsible for review and approval of all non-standard systems prior to use on the ranges. On 14 November 1961, a letter was sent by Dr. Brockway Mc Millan, Assistant Secretary of the Air Force (R&D), to the Chief of Staff indicating incompatibility in telemetry systems for weapon and space

programs and stressing the need for a plan to reduce the number of telemetry systems to the fewest possible.

On 1 December 1961, a directive was sent by AFSC to ESD appointing ESD as the Team Captain for the work outlined above. In addition, BSD, SSD, ASD, AFMTC, AFFTC, APGC, and AFSWC were directed to lend their support to ESD. A report was prepared and forwarded to AFSC and Hq USAF in April 1962. On 16 August 1962 Hq USAF approved the effort and requested on 23 August 1962 that ESD prepare an Implementation Plan to standardize USAF telemetry.

In July 1963 the Implementation Plan for Telemetry Systems Standardization was forwarded to AFSC, and the plan was put into effect by ESD immediately. Numerous working papers and technical memoranda have been produced during the past year, collecting, categorizing, and analyzing data on all available programs. This report presents a summary of the FY-64 effort on this program.

1.4 Approach to the Problem

The initial step was to collect and classify telemetry requirements on existing and planned programs. The data was then categorized and analyzed. This analysis has led to recommendations to AFSC and IRIG/TWG. These recommendations expand the capabilities of existing systems and eliminate the bulk of the existing deviations.

The recommendations also assist the ranges in planning for an economic up-dating of range equipment. At some ranges the accommodation of non-standard program requirements with present range equipment consumes an appreciable percentage of the total operating cost of the range. This effort helps minimize that cost. Present systems and proposed systems which show considerable merit are analyzed and grouped under major headings such as frequency division (FM/FM) and time division (PAM/FM) systems. Arising out of this work will be the identification of optimum modulation formats to meet the user's telemetry requirements. These will lead to the proposal of basic standard telemetry systems that will meet the bulk of future requirements.

1.5 Progress During FY-64

Characteristic telemetry link data have been obtained from the Air Force, Army, Navy, and NASA. Data from 399 links on 75 programs, incorporating 628 deviations have been categorized in the case files. These statistics clearly show the magnitude of the effort involved on the ranges in the handling of deviations, i.e., an average of 8 deviations per program and 1.6 deviations per telemetry link.

Twenty (20) recommendations for revisions to the standards have been made to the Telemetry Standards Coordination Committee,

of the National Telemetry Conference, and the IRIG FM/FM Multiplex Committee. Some of these recommendations were evaluated by the members and were discussed at the 27th meeting of IRIG/TWG in Boulder, Colorado on 13-16 July 1964.

a. The revision of the PAM/FM/FM commutation table eliminates approximately 30% of the total deviations.

b. The specification of an available IF bandwidth in all sections of the standard systems eliminates approximately 20% of the total deviations.

c. The incorporation of the 93 kc subcarrier, the expansion of the baseband to 110 kc for the FM/FM system, and the increase in deviation for ratios up to 22.5% and 30% eliminates approximately 5% of the total deviations.

d. The inclusion of all the RF frequencies assigned by the Geneva Convention eliminates approximately 5% of the total deviations.

The present effort has produced more than 40 reports, among which are 11 case reports arising out of 90 case files.

A number of studies have been sorted out as a result of this work and are scheduled for immediate performance. Hopefully, these studies will lead to improved and expanded systems and equipment.

These studies are:

1. Economical and technical evaluation of the FM/FM baseband expansion, considering constant bandwidth as well as proportional bandwidth.

2. Theoretical and practical evaluation of PAM operation of FM/FM channels to determine feasible sampling rates for each subcarrier bandwidth.

3. Investigation of future potentials of PDM and PPM data techniques.

4. Development of design and use criteria for standard telemetry systems, to be added as an appendix to the standards, and furnishing guidelines for design engineers.

ESD/MITRE has attained a capability that can be readily extended to analyze advanced telemetry requirements for the TWG and the Air Force. With advanced requirements information from TWG members and users, ESD/MITRE will conduct analyses leading to recommendations for future standards. Areas of immediate concern are high frequency vibration requirements, and PCM and PAM/FM data requirements.

1.6 Future Work

Telemetry requirements will be studied and consolidated into trend reports. All present and future systems will be studied, and the

technical and economic advantages and trade-offs will be determined and reported. Design and performance criteria will be generated, and preferred formats and design methods will be stipulated. Specific recommendations showing technical and economic justifications will be forwarded to AFSC.

2.0 CATEGORIZATION OF NON-STANDARD DATA

2.1 Approach

Raw telemetry data comprising 75 Air Force, Army, Navy, and NASA Programs with a total of 399 links were used as a basis for this report. Data were acquired from AFETR, SSD, BSD, and WSMR primarily in the form of Program Requirement Documents (PRD's) and Requirements for Work and Resources (RFWAR's).

The data were then transferred to an Overall Data Chart having a standardized column format of telemetry characteristics. A typical Overall Data Chart is shownbelow.

Data showing deviations from the IRIG 106-60 Standards (revised 1962) were extracted from the Overall Data Charts and classified as Small, Large, or Basic as defined in Section 2.2 and 2.3 of this report.

Program	Link No.	RF Carrier	RF Band width	FM/FM Subcarrier Freq.	SCO Freq. Devia.	Commutation	Modulation	IF Band	Bit Rate	Word Length	Frame Length
6	1	232.9 mc	500 kc	Chan 10, 11, 12, 13	+7.5% —	N/A	FM/FM	No Info	N/A	N/A	N/A
				A, C, E	15						
				100 KC	15						
	2	244.3 mc	500 kc	N/A	N/A	N/A	PCM FM	No Info	172.8 kbps	27 bts	320 wds

2.2 Establishment of Criteria for the Definition of Deviation Parameters

The ESD Implementation Plan for Telemetry Standardization emphasized that the major portion of Phase I would be the collection, collation, categorization, and evaluation of telemetry data. The IRIG 106-60 Telemetry Standards provide the only basic reference for determining the deviation characteristics of the assembled data. It is generally recognized that the Standards are not up-to-date. However, they represent the only detailed standards for telemetry systems equipment and characteristics and serve to minimize confusion, unnecessary and costly development, procurement and implementation of telemetry equipment.

The Implementation Plan discusses the method of classifying the telemetry deviations from the present IRIG 106-60 Standards. Briefly, small deviations in many cases may be eliminated by the proposed up-dating of the present IRIG Standards, more clearly defining certain portions of the Standards for easier interpretation and by specifically recommending the removal of deviations considered non-essential to the program. Large deviations are defined by the use of a system characteristics for unusual or abnormal purposes. It is generally recognized that large deviation types may demand abrupt changes to the Standards, require thorough analysis and testing of advanced systems and require review of the technical requirement to determine if existing equipment or systems could more economically

serve the purpose. Basic Deviations are entirely different from existing Standards. Since these deviations, in most cases, involve modulation formats, a detailed analysis is required to determine preferred formats and design methods while insuring economic feasibility. The deviations are categorized as follows:

Small Deviations

1. Not vital to program
2. Can be redesigned to Standards
3. Can be handled by ranges at a few stations usually by non-ideal but adequate techniques

Large Deviations

1. Vital to program
2. Cannot be redesigned to Standards
3. May be handled by ranges at a few stations, usually by non-ideal techniques or by timely procurement

Basic Deviations

1. Vital to program
2. Cannot be redesigned to Standards
3. Usually cannot be handled by ranges
4. Is probably a new modulated format or system, may have general merit and may be suitable for system tests.

2.3 Specific Definitions of Deviations

2.3.1 Sub-Carrier Frequencies and Percent Modulation

2.3.1.1 Criteria for "Small" Deviations

A non-Standard SCO frequency (See Table 1 for IRIG Standard SCO frequencies) between 340 cps and 110 kc with a $\pm$ 7.5%, or less deviation at SCO frequencies below 22 kc, or $\pm$ 7.5%/$\pm$ 15% or less

deviation at SCO frequencies above 22 kc, or with no deviation percentage quoted is classified as a small deviation. In addition, any Standard SCO frequency below 22 kc with a 2.5% or less deviation or SCO frequency above 22 kc with a 5% or less deviation is also classified as a small deviation.

The lowest IRIG SCO frequency is 400 cps (band 1) and the lower limit of that band is 370 cps when the maximum permissable deviation of $\pm$ 7.5% is used. It is felt, however, that range instrumentation facilities can presently accommodate frequencies down to 340 cps. Similarly, the IRIG upper limit of SCO usage is 70 kc, resulting in a maximum excursion to 80.5 kc when used with the permissible $\pm$ 15% deviation. Furthermore, for magnetic tape compensation purposes, a 100 kc reference frequency is sometimes transmitted for flutter compensation. Magnetic recorders on the ranges can readily accommodate frequencies up to 110 kc and for this and the above reasons, the normal baseband has been defined as 340 cps to 110 kc.

Summarized Criteria for Small Deviations;

a. Non-Standard frequency

b. With $\leq \pm$ 7.5% below 22 kc or $\leq \pm$ 7.5%/ $\pm$ 15% above 22 kc

c. Between 340 cps and 110 kc

or

a. Standard frequency

b. Between 340 cps and 110 kc

c. With $\leq \pm$ 2.5% below 22 kc or $\leq \pm$ 5% above 22 kc

2.3.1.2 Criteria for "Large" Deviations

Any Standard or non-Standard SCO frequency between 340 cps and 22 kc with greater than 7.5% deviation or between 22 kc and 110 kc with greater than 15% deviation is classified as a large deviation. The use of larger deviations is to be avoided because of crosstalk and because present instrumentation equipment are not designed for larger deviations. Any non-Standard SCO frequency larger than 110 kc or less than 340 cps is also classified as a large deviation. These are considered as large deviations because of the present range recording capabilities of the much-used FR 100 recorders are limited to this frequency response.

Summarized criteria for Large Deviations

a. Standard or non-Standard frequency

b. Between 340 cps and 110 kc

c. With $> \pm$ 7.5% below 22 kc or $> \pm$ 15% above 22 kc

or

a. Non-Standard frequency < 340 cps

or

a. Non-Standard frequency > 110 kc

TABLE 1

STANDARD IRIG SUBCARRIER BANDS

BAND	CENTER FREQ	LOWER LIMIT	UPPER LIMIT	FREQUENCY RESPONSE
1	400	370	430	6.0
2	560	518	602	8.4
3	730	675	785	11
4	960	888	1,032	14
5	1,300	1,202	1,398	20
6	1,700	1,572	1,828	25
7	2,300	2,127	2,473	35
8	3,000	2,775	3,225	45
9	3,900	3,607	4,193	59
10	5,400	4,995	5,805	81
11	7,350	6,799	7,901	110
12	10,500	9,712	11,288	160
13	14,500	13,412	15,588	220
14	22,000	20,350	23,650	330
15	30,000	27,750	32,250	450
16	40,000	37,000	43,000	600
17	52,000	48,562	56,438	790
18	70,000	64,750	75,250	1,050
A	22,000	18,000	25,300	660
B	30,000	25,500	34,500	900
C	40,000	34,000	46,000	1,200
D	52,000	44,625	60,000	1,600
E	70,000	59,300	80,500	2,100

Note: 1. Frequency response is based on maximum deviation and deviation ratio of 5.

2. Bands A through E are optional and may be used by omitting adjacent bands as follows:

Bands Used	Omit Bands
A	13, 15 and 16
B	14, 16, A and C
C	15, 17, B, D
D	16, 18, C and E
E	17 and D

2.3.2 Adjacent Channel Violation

The IRIG 106-60 Standards as shown in Table I allow the use of the upper five SCO bands at ± 15% deviation provided the adjacent channels on either side are not used. Violations of the footnote to Table I relating to channel usage are considered as small adjacent channel violations.

The average ratio of separation between SCO channels is 1.35 with the exception of the spacing between the 14.5 and 22 kc channels where the ratio is 1.57. This abnormal mutual ratio was set to leave a gap for the 17 kc AM speed compensation frequency having a total deviation of ± 0.8 %. The Standards clearly state in the footnote to Table I, that the simultaneous use of the adjacent channels, 14.5 kc ± 7.5% and 22 kc ± 15% is prohibited. However, this particular violation of the IRIG 106-60 occurred 40 times and was the only type adjacent channel violation. It should be noted, however, that the Standards prior to the June 1962 revision permitted the simultaneous use of channels and 13.

Summarized Criteria for Small Deviations:

a. Violation of Footnote to Table I

2.3.3 RF Carrier Frequencies

2.3.3.1 VHF Band

Section 2.1.1.6 of the IRIG 106-60 Standards precisely defined the VHF frequencies for telemetry use. Deviations from these allocated frequencies have been classified as small. This

classification is subject to controversy in that the non-Standard frequency more than likely can be accommodated on the range. Moreover, approval by a frequency coordination committee must be obtained prior to using the requested frequency. Nonetheless, the IRIG Standards have defined the limits for adherence.

Summarized criteria for small deviations:

Any other number between 216.5 and 259.7 than those stated.

For convenience, the VHF frequency assignments in the Standards are given in Table II below:

TABLE II

ASSIGNMENT FOR THE 216-260 MCS FREQUENCY BAND

216.5	223.0	228.2	237.8	248.6
217.0	223.0	229.9	240.2	249.1
217.5	224.0	230.4	241.5	249.9
218.0	224.5	230.9	242.0	250.7
218.5		231.4	243.8	251.5
219.0		231.9	244.3	252.4
219.5		232.4	244.8	253.1
220.0	225.0	232.9	245.3	253.8
220.5	225.7	234.0	246.8	255.1
221.0	226.2	235.0	246.3	256.2
221.5	226.7	235.5	246.8	257.3
222.0	227.2	236.2	247.3	258.5
222.5	227.7	237.0	247.8	259.7

2.3.3.2 UHF Band

The present IRIG Standards stipulate the frequency assignments for the UHF band by stating that the channel spacing in both the 1435-1535 mc and 2200-2300 mc band shall be at 1 mc increments. End point frequencies are assumed to be 1435.5-1534.5 and 2200.5-2299.5 mc. UHF band frequencies differing from the above values are classified as small deviations. It is realized that the levying of stringent parameters on the UHF band carrier frequencies is a subject of concern; however, establishment of a precedent is mandatory with the planned shift to UHF in the near future to preclude unnecessary usage.

Summarized criteria for small deviations:

Any other number than 1435.5, 1436.5, ...1534.5 or 2200.5, 2201.5, ... 2299.5.

2.3.3 Miscellaneous Carrier Frequencies

RF carrier frequencies outside the VHF (216-260 mc) and UHF (1435-1535 mc) (2200-2300 mc) bands are classified as small deviations. The majority of the frequencies are among those allocated by the International Telecommunication Union Geneva Convention.

Summarized criteria for small deviations:

All other RF carrier frequencies (and their bandwidths).

2.3.4 RF Bandwidths

2.3.4.1 Criteria for Small Deviations

Section 2.1.1.3 of the IRIG 106-60 Standards (Appendix 1) states that "the bandwidth of the modulated carrier shall

not exceed 500 kc. Carrier components appearing outside the 500 kc bandwidth must meet the limits for spurious and harmonic emissions--" which defines the -55db points outside this maximum modulation bandwidth. Therefore, the following parameters define a small deviation of the RF bandwidth (VHF) to be any value less than 500 kc but greater than 100 kc. There are several contingencies surrounding the selection for this limit. For example, it is recognized by the evaluation of the data that attempts have been made to relate transmitter bandwidth with receiver IF bandwidths. Also, the format in many PRD's providing certain program characteristics is confusing as to the specifications for RF transmitter bandwidths.

Appendix I, Section 2. 3. 3. 2 of the IRIG 106-60, limits the RF modulation bandwidth (UHF) to 1 mc maximum for narrowband application. Also, restrictions for spurious and harmonic emissions will be adhered to (-55 db points). Thus, values of RF bandwidth less than one (1) mc will be considered small deviations. A limit of 200 kc has been established as the lower cut-off point when considering the 7 db reduction in S/N when only a 1 mc receiver is available.

Summarized criteria for small deviations:

VHF - Values between 100 kc and 500 kc.

UHF - All values between 200 kc and 1 mc.

2.3.4.2 Criteria for Large Deviations

Referring to Section 2.1.1.3 of IRIG 106-60, the RF modulation bandwidth within the VHF band is limited to 500 kc. Restructions due to spurious and harmonic emission are given. In classifying the large RF bandwidths, it was decided that any value greater than 500 kc or less than 100 kc must be considered as a large deviation.

With regard to the UHF bandwidth stipulations as delineated in Appendix I, Section 2.3.3.2, IRIG 106-60, the following classifications were made: values larger than 1000 kc and values below 200 kc are large deviations. It is realized in the case of larger than 1000 kc bandwidths that certain wideband applications are required and are necessary. Attempts must be made to preclude future controversy when the shift to UHF frequencies is implemented.

Summarized criteria for large deviations:

VHF - All values above 500 kc, all values below 100 kc

UHF - All values above 1 mc, all values below 200 kc

2.3.5 Commutation Formats (PAM/FM/FM and PDM/FM/FM).

This section deals with the classification of deviations in PAM and PDM commutation formats as used in the PAM/FM/FM and PDM/FM/FM versions of the FM/FM system. These formats mean

time division use of the subcarrier channels with the input data sampled so that a stream of data pulses from separate inputs is generated; the data magnitude being in the pulse amplitude for PAM and in the pulse width for PDM.

The sampling is performed by a commutator. The commutation format is defined by the number of samples per frame and the frame rate. The commutation rate equals the number of samples in each frame times the frame rate. Frames of data pulses are defined by the synchronization pulses. Table II (IRIG 106-60) listed eight Standard PAM commutation formats: 18x5, 18x10, 18x25, 30x2.5, 30x10, 30x5, 30x20, and 30x30. Standard PDM formats are: 30x30, 45x20, 60x15, and 90x10. Thus, the lowest Standard commutation rate of 2.5 frames per second, is determined by the maximum storage time allowable without incurring appreciable loss of stored sample amplitude. The combinations of maximum allowable commutation rate and minimum allowable frame rate are used as a basis for classifying deviations in commutation formats.

Only one (1) program showed PDM/FM commutation deviations. No other PDM/FM or PAM/FM deviations were found in the collected data.

Summarized criteria for deviations:

Non-Standard Commutation Formats

Large - Any deviations from combinations shown.

Sampling Rate and IF Bandwidth

Large - Any PAM/FM IF bandwidth not listed in Table IV

or

Any sampling rate not between 1/3 and 1/23 of required IF bandwidth.

Basic - Any combination of the two large deviations above

Frame Length

Large - Any frame length greater than 130 primary or 130 sub-commutated channels.

2.3.5.1 Non Standard Commutation Formats

2.3.5.1.1 Criteria for Small Deviations

Commutation formats differing from the eight Standard PAM formats or the four Standard PDM formats but having a commutation rate of 900 samples per second, or less, and a frame rate of 2.5 frames per second, or greater, are classified as small deviations.

Summarized criteria for small deviations:

Sampling rate $\leq$ 900/sec

Frame rate $\geq$ 2.5/sec

2.3.5.1.2 Criteria for Large Deviation

Commutation formats which have a commutation rate of 900 samples per second, or less, and a frame rate less than the lowest Standard rate of 2.5 frames per second are classifed as large deviations. In addition, a commutation format having a commutation rate greater than the highest Standard rate of 900 samples per second and a frame rate of 2.5 frames per second, or greater, is also classified as a large deviation.

Summarized criteria for large deviation:

Sampling rate $\leq$ 900/sec

Frame rate $<$ 2.5/sec

OR

Sampling rate $>$ 900/sec

Frame rate $\geq$ 2.5/sec

2.3.5.1.3 Criteria for Basic Deviations

A commutation format having both a commutation rate greater than the highest Standard rate of 900 samples per second and a frame rate smaller than the lowest Standard frame rate of 2.5 frames per second is classified as a basic deviation.

Summarized criteria for basic deviations:

Sampling Rate > 900/sec

Frame rate < 2.5/sec

2.3.5.2 Standard Commutation Formats on Improper Sub-Carrier

Tables II and III of the IRIG 106-60 Standards specify the lowest recommended subcarrier band for use with specific PAM/FM/FM and PDM/FM/FM commutation formats. The general "rule of thumb" followed in the Standards is that the maximum commutation rate on a particular channel should be no greater than one-half the frequency response of that channel given in Table I, IRIG 106-60. The ratios of commutation rate to channel frequency response for the deviating data were between 0.67 and 1.37 with the former ratio dominating. Because it does not appear that these deviations are technically unsound, they have been classified as small deviations.

2.3.6 Pulse Code Modulation

2.3.6.1 Bit Rate and IF Bandwidth

Section 5 of the IRIG 106-60 Standards specifies certain parameters as guidelines for the use of PCM systems. It must be realized that the use of pulse code modulated systems has been

augmented in the past 2 or 3 years with the shift from ballistic to space systems. As a result, the present Standards which are adhered to by a few programs, nonetneless, must be modified to meet future PCM requirements.

The Standards state that the bit rates and corresponding IF bandwidths must be selected from the IRIG 106-60 as shown in Table III below.

TABLE III

PCM BIT RATE AND RECEIVER IF BANDWIDTH

Bit Rate (bits per sec)	Receiver IF Bandwidth (cps, 3 db point)
8, 000 and lower	12, 500 (and as required for lower bit rates)
8, 000 to 65, 000	25, 000 - 50, 000 - 100, 000
50, 000 to 330, 000	100, 000 - 300, 000 - 500, 000
320, 000 to 800, 000	500, 000 - 1, 000, 000 - 1, 500, 000

Note: IF Bandwidth of 1 mc and greater for use in 1435-1535 mc, and 2200-2300 mc band only.

The Standards further recommend that a bit rate equal to the IF bandwidth at the 3 db points with a division factor from 1.5-3.3 be utilized.

Table V of IRIG 106-60 defines 8 values of IF bandwidth with corresponding bit rates. Any deviations from these specifications must be treated as large because odd values of bandwidth not listed involve the purchase of new IF strips.

Summarized criteria for large deviations:

Bit Rate and IF Bandwidth

Large - Any deviation from IF bandwidths of Table V of IRIG 106-60

or

Any deviation in bit rate from 1/1.5 to 1/3.3 times a Standard IF bandwidth.

2.3.6.2 Frame Length, Word Length, and Synchronization

In Section 5, the IRIG Standards clearly state that "the number of bits per frame shall not exceed 2,048, including

A. 2 Adjacent Channel Violations (FM/FM, Table I, IRIG 106-60)

All Small if:

a. Violation of footnote to Table I.

A. 3 Table II and III Commutation Deviations (PAM/FM/FM and PDM/FM/FM)

SMALL	LARGE	BASIC
a. Sampling rate $\leq$ 900/sec.	a. Sampling rate $\leq$ 900/sec.	a. Sampling rate > 900/sec.
b. Frame rate $\geq$ 2.5/sec.	b. Frame rate < 2.5/sec.	b. Frame rate < 2.5/sec.
c. Samples/frame $\leq$ 90	OR	
	a. Sampling rate > 900/sec.	
	b. Frame rate $\geq$ 2.5/sec.	

A. 4 Standard Commutation Formats on Improper Sub-carriers

All Small

B. STANDARD ANALOG TIME DIVISION SYSTEMS (PCM/FM, PAM/FM)

B.1 Non-Standard Commutation Formats (PDM/FM, IRIG 106-60, Section 3.2)

Large - Any deviations from combinations shown.

B.2 Sampling Rate and IF Bandwidth (PAM/FM, IRIG 106-60, Section 4.2)

Large - Any PAM/FM IF bandwidth not listed in Table IV, page 13.

or

Any sampling rate not between 1/3 and 1/23 of required IF bandwidth.

Basic - Any combination of the two large deviations above.

B.3 Frame Length (PAM/FM, IRIG 106-60, Section 4.4)

Large - Any frame length greater than 130 primary of 130 sub-commutated channels.

C. STANDARD PULSE CODE SYSTEMS (PCM/FM)

C.1 Bit Rate and IF Bandwidth (PCM/FM, IRIG 106-60, Section 5.2, and Table V)

Large - Any deviation from IF bandwidths of Table V.

or

Any deviation in bit rate from 1/1.5 to 1/3.3 times a Standard IF bandwidth.

C.2 Frame Length, Word Length, and Synchronization (PCM/FM, 106-60, Sections 5.4, 5.5)

Large - Any deviation from Standards.

Word Length	6-64 bits
Frame Length	2048 bits/frame max
Synchronization	33 bits max

D. RF CARRIER FREQUENCY AND RF BANDWIDTH (APPENDIX I, IRIG 106-60)

D.1 RF Carrier Frequency

Small - Any other number between 216.5 and 259.7 than those stated.

or

Any other number than 1435.5, 1436.5, ... 1534.5, or 2200.5, . . . 2299.5.

or

All other RF carrier frequencies (and their bandwidths).

D.2 RF Bandwidths (VHF and UHF) .

VHF RF Bandwidths

Large - All values above 500 kc.

or

All values below 100 kc.

Small - Values Between 100 kc and 500 kc.

UHF RF Bandwidths

Large - All values above 1 mc.

or

All values below 200 kc.

Small - All values between 200 kc and 1 mc.

E. NON-IRIG MODULATION FORMATS

Basic - All non-IRIG modulation formats including all data on that link.

3.0 EXAMPLES OF NON-STANDARD DATA

3.1 Specific Deviations by Type and Occurrence

Table IV identifies the widely varying types of deviations from the IRIG-106-60 Standards that have appeared in 75 Army, Navy, Air Force, and NASA programs. These deviations are broken down into nine working categories and are, in addition, grouped into small, large and basic parameters. Numerical values have been provided which serve to indicate the frequency of occurrence and emphasize the necessity for the specific recommendations and suggestions made in Section 4.0. Security regulations prevent association of actual values of non-Standard data with certain individual programs.

Examination of the data reveals that the majority of deviations occurring in the selection of commutation formats result from the outdated portion of the IRIG-106-60 Standards dealing with commutation values. Development of commutation/decommutation equipment has advanced so rapidly in the past two or three years that the present commutation capabilities are not reflected in the Standards.

TABLE V

VARIATION OF NON STANDARD DATA

A. Sub-Carrier Frequencies and Percent Modulation

Small

Type	Occurrence
.760 kc ± 7.5%	1
2.20 kc ± 7.5%	1
7.3 kc ± 6%	1
7.3 kc ± 7.5%	2
17.5 kc ± ?%	1
22.130 kc ± ?%	2
22.662 kc ± ?%	2
24.588 kc ± ?%	2
25.0 kc ± 8%	24
70.5 kc ± 7.5%	5
85.0 kc ± 15%	2
93.0 kc ± 7.5%	4
98.0 kc ± 15%	3
100.0 kc ± ?%	2
100.0 kc ± 15%	3
Total	55

Large

20.0 kc ± 15%	3
25.0 kc ± 16%	2
27.0 kc ± 40%	1
52.5 kc ± 40%	1
54.0 kc ± 40%	2
70.0 kc ± 30%	1
98.0 kc ± 40%	1
124.0 kc ± ?%	2
124.0 kc ± 4.8%	2
125.0 kc ± 7.5%	2
165.0 kc ± 7.5%	4
225.0 kc ± 2.2%	2
Total	23

B. Adjacent Channel Violations

Small

Type	Occurrence
14.5 kc ± 7.5% and 22 kc ± 15%	40
	40

C. Commutation Formats

C.1 Non Standard PAM/FM/FM and PDM/FM/FM commutation formats.

Small

Type	Occurrence
24 x 2.5 = 60	1
26 x 2.5 = 65	1
45 x 2.5 = 112.5	4
24 x 5 = 120	1
26 x 5 = 150	2
30 x 5 = 150	1
60 x 2.5 = 150	11
20 x 10 = 200	1
60 x 4 = 240	1
24 x 10 = 240	1
26 x 10 = 260	2
27 x 10 = 270	2
28 x 10 = 280	10
10 x 30 = 300	2
15 x 20 = 300	1
60 x 5 = 300	70
45 x 10 = 450	2
60 x 10 = 600	10
34 x 20 = 680	1
35 x 20 = 700	1
12 x 60 = 720	1
26 x 30 = 780	1
8 x 100 = 800	1
43 x 20 = 860	1
45 x 20 = 900	1
90 x 10 = 900	1
Total	131

Large

Type	Occurrence
16 x 1/40 = .4	2
3 x 1 = 3	4
30 x 1/4 = 7.5	1
60 x 1/8 = 7.5	4
8 x 1 = 8	2
18 x 1/2 = 9	2
90 x 1/8 = 11.25	2
32 x 1/2 = 16	1
30 x 5/8 = 18.75	1
60 x 0.4 = 24	3
30 x 1 = 30	1
60 x 1/2 = 30	8
60 x 1 = 60	17
45 x 2 = 90	3
90 x 1 = 90	2
90 x 1.25 = 112.5	9
Total	62

Large

Type	Occurrence
60 x 30 = 1800	8
30 x 120 = 3600	1
Total	9

C.2 Commutation Formats (Standard) on Improper Sub-Carriers

Small

Type	Occurrence
30 x 5 on 14.5 kc ± 7.5%	1
28 x 10 on 30 kc ± 7.5%	7
30 x 10 on 22 kc ± 7.5%	1
30 x 10 on 30 kc ± 6%	1

30 x 10 on 30 kc ± 7.2%		1
30 x 10 on 30 kc ± 7.5%		4
30 x 30 on 22 kc ± 15%		1
30 x 30 on 30 kc ± 7.5%		1
30 x 30 on 70 kc ± 6%		1
90 x 10 on 10.5 kc ± ?%		2
	Total	20

C.3 PDM/FM and PAM/FM Non-Standard Commutation Formats

Large

Type		Occurrence
30 x 24 = 720		8
28 x 30 = 840		1
	Total	9

D. R-F Carrier Frequencies (Within VHF Band)

Small

Type		Occurrence
227.5 mc		1
228.5 mc		1
229.6 mc		1
229.7 mc		1
230.0 mc		3
232.5 mc		1
232.9 mc		2
233.5 mc		1
239.0 mc		1
239.5 mc		1
242.5 mc		2
243,6 mc		1
254.4 mc		1
256.22 mc		1
258.3 mc		1
	Total	19

D.1 R-F Carrier Frequencies (Within UHF Band)

Small

Type	Occurrence
2231.6 mc	1
Total	1

D.2 R-F Carrier Frequencies and Bandwidth (Outside VHF/UHF).

Small

Type	Occurrence
1 - 12 mc (?)	1
16-17 mc (?)	1
136 - 137 mc (100 kc)	3
136.020 mc (4.5 kc)	1
136.080 mc (100 kc)	1
136.110 mc (2kc)	1
136.140 mc (1.152 kc)	1
136.170 mc (30 kc)	2
136.230 mc (30 kc)	1
136.275 mc (30 kc)	1
136.290 mc (30 kc)	1
136.320 mc (100kc)	1
136.470 mc (?)	1
136.590 mc (100 kc)	1
136.620 mc (1.152 kc)	1
136.650 mc (50 kc)	1
136.710 mc (100 kc)	1
136.740 mc (40 kc)	1
136.740 mc (100 kc)	1
136.800 mc (50 kc)	1
136.920 mc (6 kc)	1
136.980 mc (2 kc)	2
149.988 mc (50 kc)	1
150.0 mc (50 kc)	1
214.0 mc (?)	1
316.9 mc (?)	1
400.0 mc (?)	1

400 - 402 mc (4 kc)	1
400. 250 mc (256 kc)	1
400. 850 mc (256 kc)	1
959. 52 mc (470 kc)	1
960. 05 mc (100, 000 kc)	2
960. 5 mc (?)	1
960. 58 mc (470 kc)	1
1700 - 1710 mc (3, 000 kc)	2
4997 mc (6, 000 kc)	1
5000 mc (?)	1
5000 mc (6, 000 kc)	1
5003 mc (6, 000 kc)	1
9320 mc (22, 500 kc)	1
13, 471 mc (1240 kc)	1
13, 479 mc (1240 kc)	1
16-17 kmc (?)	1
Total	49

E. R-F Bandwidths (VHF/UHF)

Small (VHF)

Type	Occurrence
100 kc	1
108 kc	2
125 kc	3
160 kc	2
250 kc	42
256 kc	2
282 kc	6
300 kc	36
330 kc	8
250 kc	4
Total	116

Small (UHF)

Type	Occurrence
250 kc	1
Total	1

Large (VHF)

Type	Occurrence
1 - 80 kc	1
2 kc	1
10 kc	2
15 kc	1
20 - 33 kc	1
50 kc	1
Low Freq - 70 kc	1
1000 kc	2
Total	10

Large (UHF)

Type	Occurrence
3 mc	1
± 10 mc	1
48 mc	1
Total	3

F. Bit Rate and IF Bandwidth (PCM/FM)

Large

Type	Occurrence
60 kc	2
35,840 **bps** in 300 kc	2
43,200 **bps** in 500 kc	1
Total	5

G. Frame Length, Word Length, and Synchronization

G. 1. Frame Length (Bits/Frame)

Large

Type	Occurrence
3520	4
3584	2
8640	8
10368	2
Total	16

H. Non-IRIG Modulation Formats

Basic

Type	Occurrence
PPM	2
PAM-PCM/FM/FM	1
PCM	2
PAM/FM/PM	8
PFM	3
PAM/AM	1
PAM/FM/AM	3
Square Wave PM	1
FM/AM	3
PCM/PS/AM	1
AM/FM	3
Pulse and FM	2
FM	4
PAM/FM/FM & FM	2
PAM/FM/FM & Digital	1
SSB/FM	4
PCM/FM/PM	2
CW	1
PAM-PCM/FM/FM	1
PPM/AM	3
FM/FM/FM	3
PCM/FM (Digital)	1
PM/FM	6
Total	59

Table VI below shows the occurrence of deviations by type as defined in Section 2.3. This table represents a categorization of 628 deviations taken from 399 links on 75 Air Force, Army, Navy, and NASA programs and provides an insight into the relative importance of eliminating the various deviations.

TABLE VI

OCCURRENCE OF DEVIATIONS BY TYPE

	Occurrence	Percent Small, Large, Basic	Percent Total
1. Small Deviations			
a. Sub-Carrier Frequencies and Percent Deviations.	55	12.7	8.8
b. Adjacent Channel Violations.	40	9.3	6.4
c. RF Carrier Frequencies.			
(1) Standard Bands.	20	4.6	3.2
(2) Non-Standard Bands.	49	11.3	7.8
d. RF Bandwidths (VHF).	116	26.8	18.5
e. RF Bandwidths (UHF).	1	0.2	0.1
f. Commutation Formats (PAM/FM/FM and PDM/FM/FM).	151	35.1	24.0
	432	100.0	68.8
2. Large Deviations			
a. Sub-Carrier Frequencies and Percent Deviations.	23	16.8	3.7
b. Commutation Formats	80	58.4	12.7
c. Bit Rate and IF Bandwidths (PCM/FM).	5	3.6	0.8
d. Frame Length, Word Length and Synchronization (PCM/FM).	16	11.7	2.5
e. RF Bandwidth (VHF).	10	7.3	1.6
f. RF Bandwidth (UHF).	3	2.2	0.5
	137	100.0	21.8
3. Basic Deviations			
a. Non-IRIG Modulation Formats	59	100.0	9.4
	59	100.0	9.4
	628		100.0

3.2 DEVIATIONS BY PROGRAMS AND LINKS

Table VII is a tabulation of the 75 programs by link, number of deviations per link and the classification of these deviations. Stringent security regulations preclude the identification of specific deviations with an individual program/link. The numerical assignment of a link does not necessarily indicate its actual assignment within the program. These links were numbered consecutively as interpreted from the Program Requirement Documents (PRD).

The primary objective of this table is to focus attention on programs containing excessive numbers of deviations to point out the economic impact these deviations have on the range operations.

TABLE VII

DEVIATIONS BY PROGRAMS AND LINKS

Program (Non-IRIG/ Total Link)		Small	Large	Basic
#1 (18/18)	Link No.			
	1	1		1
	2	1		1
	3	1		
	4	1		
	5	1		1
	6	1		
	7	1		
	8	1		
	9	1	1	1
	10	1	1	1
	11	1		
	12	2		
	13	1		1
	14	1		1
	15	3		
	16	2		
	17	2		
	18	2		
Sub-Total		24	2	7
#2 (16/17)	Link No.			
	1	1		
	2	1		1
	3	1		
	4	1		1
	5	1		
	6	1		1
	7	1		1
	8	3		1
	9	2		
	10	2		
	11	2		
	12	4		
	13	3		
	14		1	

#2 (Continued) (16/17) Link No.	Small	Large	Basic
16	1		
17	1		1
Sub-Total	26	1	6
#3 (42/51) Link No.			
1a	2		
2	1	2	
2a	4		
3	1	2	
3a	3		
4			1
4a	1		
5			1
5a	4		
6	1		
6a	1		
7	1	2	
7a		1	
8	1	3	
8a	1		
9a	1		
10a	3		
11a	4		
12a	4		
13a	4		
14a	4		
16a	1		
17a	1		
18a	1		
20a	1		
21a	1		
22a	1		
23a	1		
24a	1		
28a	2		
29a	2		
30a	1		
31a	1		
32a	1		

#5 (Continued)

(42/51) Link No.	Small	Large	Basic
33a	1		
34a	1		
35a	1		
36a	4		
36a	4		
38a	4		
39a	1		
41a	2		
Sub-Total	74	10	2

#4 (3/3) Link No.

1	1		
2	1		
3		1	1
Sub-Total	2	1	1

#5 (5/5) Link No.

1	1		
2	1		
3	1		
4	1	1	1
5	1	1	1
Sub-Total	5	2	2

#6 (3/3) Link No.

1	3		
2	2		
3		1	
Sub-Total	5	1	0

#7 Link No.

2	1		
3		1	
4	1		
5	1		
8		1	1
10		1	1
Sub-Total	3	3	2

#8 (12/22) Link No.	Small	Large	Basic
1	1	1	
2	1	2	
3	1	1	
4	1	1	
5	1		
6	1		
8	2		
8a	1		
9		1	
9a	5		
10	1		
10a	1		
Sub-Total	16	6	0

#9 (6/6) Link No.			
1	1		
2	1		
3	1		
4	1		
5	1		
6	1		1
Sub-Total	6	0	1

#10 (10/10) Link No.			
1	1	4	
2	2	2	
3	6	1	
4			1
5	2	2	
6	2	2	
7	1	5	
8	1	5	
9	1	1	1
10	1	1	1
Sub-Total	17	23	3

#11 (2/2)	Link No.			
	1	2		
	2	2		
Sub-Total		4	0	0
#12 (3/4)	Link No.			
	1		2	
	3		1	
	4		2	1
Sub-Total		0	5	1
#13 (13/14)	Link No.			
	1		2	
	2	1		
	3	3		
	4	3		
	5	3		
	6	3		
	7	2		
	8	2		
	10			1
	11			1
	12	1		
	13	2		
	14	2		
Sub-Total		22	2	2
#14 (11/13)	Link No.	1		
	1a	1		
	2	1		
	2a	1		
	3		1	
	4a		1	
	6a	2	1	
	7a		3	
	8a		1	
	9a	2	1	
	10a		1	
Sub-Total		8	9	0

#15 (7/10) Link No.	Small	Large	Basic
1	6		1
2	3	1	
3	2		
4	1		
6	1		
9	2	1	
10	3		
Sub-Total	18	2	1

#16 (7/12) Link No.			
1	2		
2	1		
2a	6	2	
3		1	
4		1	
4a		2	
6a		2	
Sub-Total	9	8	0

#17 (3/4) Link No.			
1	6		
3	2		
4	2		
Sub-Total	10	0	0

#18 (1/4) Link No.			
1	5	1	
Sub-Total	5	1	0

#19 (2/2) Link No.			
1	5	1	
2		1	1
Sub-Total	5	2	1

#20 (2/2) Link No.

	1	1	
	2	3	
Sub-Total		4	0	0

#21 (5/5) Link No.

	1		1
	2	1	
	3	1	
	4	2	
	5	2	
Sub-Total		0	6	1

#22 (1/1) Link No.

	1	1		
Sub-Total		1	0	0

#23 (3/5) Link No.

	3	1	
	4	1	
	5	1	
Sub-Total		3	0	0

#24 (1/2) Link No.

	2	1		
Sub-Total		1	0	0

#25 (2/5) Link No.

	2a	2	
	3a	1	
Sub-Total		3	0	0

#26 (2/2)	Link No.	Small	Large	Basic
	1a	1	2	1
	2a	1	2	1
Sub-Total		2	4	2
#27 (2/2)	Link No.			
	1a	1		
	2a	1		
Sub-Total		2	0	0
#28		24		
Sub-Total		24		

#29 (2/2)	Link No.			
	1	1		
	2	1		
Sub-Total		2		
#30 (2/2)	Link No.			
	1	1		
	2	3	1	
Sub-Total		4	1	
#31 (5/5)	Link No.			
	1	1	1	
	2	1	1	
	3	1	2	
	4	1		1
	5	1	1	
Sub-Total		5	5	1

#32 (7/7) Link No.	Small	Large	Basic
1a	1		
2a	1		
3a	1	5	
4a	5		
5a	1	1	
6a	1	4	
7a	2		1
Sub-Total	12	10	1

#33 (6/6) Link No.	
1a	1
2a	4
3a	1
4a	4
5a	2
6a	2
Sub-Total	14

#34 (9/9) Link No.			
1a	4	2	
2a	4	2	
3a	1		
4a	1		
5a	2		
6a	2		
7a	2		
8a	1	2	
9a		1	1
Sub-Total	17	7	1

#35 (8/8)	Link No.	Small	Large	Basic
	1a	5	5	
	2a		2	1
	3a	1		
	4a		1	
	5a	2		
	6a	4		
	7a	1		1
	8a	2		1
Sub-Total		15	8	3

#36 (4/5)	Link No.	
	1	
	2a	1
	3a	1
	4a	1
	5a	4
Sub-Total		7

#37 (3/3)	Link No.		
	1a	1	
	2a	1	1
	3a	1	1
Sub-Total		3	2

#38 (4/5)	Link No.		
	1a	1	1
	2a	1	1
	3a	1	1
	4a	2	
Sub-Total		5	3

WSMR

Program	Small	Large	Basic
#39 (1/2) Link No.			
2		1	
#39.2 (1/2) Link No.			
2		1	
#39.3 (1/2) Link No.			
2		1	
#39.4 (1/1) Link No.			
1	1		
#39.5 (1/1) Link No.			
1	1		
#39.6 (1/3) Link No.			
2	1		
#39,7 (2/4) Link No.			
3	1		
4	1		
#39.8 (2/3) Link No.			
2	1		
3	1		
Sub-Total	7	3	

#40 (2/2) Link No.	Small	Large	Basic
1	1		
2	1		
Sub-Total	2		

#41 (1/2) Link No.			
2	2		
Sub-Total	2		

#42 (1/5) Link No.			
5	1		
Sub-Total	1		

#44 (2/4) Link No.			
1		1	
3		1	
Sub-Total		2	

#45 (1/1) Link No.			
1	1		
Sub-Total	1		

#46 (3/4) Link No.			
1		1	
2		1	
3		1	
Sub-Total		3	

#47 (8/8) Link No.	Small	Large	Basic
1		1	
2		1	
3		1	
4		1	
5		1	
6		1	
7		1	
8		1	
Sub-Total		8	

#48 (1/1) Link No.			
1		1	
Sub-Total		1	

#49 (1/3) Link No.			
3		1	
Sub-Total		1	

#50 (1/2) Link No.			
2	1		
Sub-Total	1		

#51 (1/4) Link No.			
2		1	
Sub-Total		1	

#52 (4/4) Link No.			
1	1		1
2	1		
3			1
4			1
Sub-Total	2		3

#53 (1/2) Link No.	Small	Large	Basic
1	1		
Sub-Total	1		

#54 (2/3) Link No.			
2			1
3	2		
Sub-Total	2		1

#55 (2/3) Link No.			
2	1		
3	1		
Sub-Total	2		

#56 (3/5) Link No.			
2	1		
3	1		
5	1		
Sub-Total	3		

#57 (1/2) Link No.			
2	1		
Sub-Total	1		

#58 (1/1) Link No.			
1	1		
Sub-Total	1		

#59 (1/1) Link No.			
1	1		
Sub-Total	1		

#60 (1/1) Link No.			
1	1		
Sub-Total	1		

#61 (1/1) Link No.	Small	Large	Basic
1	1		
Sub-Total	1		

#62 (4/4) Link No.			
1	1		
2	1		
3	1		
4	1		
Sub-Total	4		

#63 (2/2) Link No.			
1	1		
2	1		
Sub-Total	2		

#64 Link No.			
1	2		
Sub-Total	2		

#65 (1/1) Link No.			
1	1		
Sub-Total	1		

#66 (1/1) Link No.			
1	1		
Sub-Total	1		

#67 (1/4) Link No.			
1	1		
Sub-Total	1		

#68 (3/3) Link No.	Small	Large	Basic
1	1		
2			1
3			1
Sub-Total	1		2

#69 (1/1) Link No.			
1	1		
Sub-Total	1		

#70 (2/2) Link No.			
1	1		
2			1
Sub-Total	1		1

#71 (3/3) Link No.			
1	1		
2	1		
3	1		
Sub-Total	3		

#72 (1/2) Link No.			
2			1
Sub-Total			1

#73 (6/6) Link No.			
1			1
2			1
3			1
4			1
5			1
6			1
Sub-Total			6

#74 (1/1) Link No.			
1			1
Sub-Total			1

#75 (1/4)	Link No.	Small	Large	Basic
	3	1		
Sub-Total		1		
Total (315/399)		432	137	59

4.0 RECOMMENDATIONS

4.1 Recommendations for Revision of the IRIG 106-60 Telemetry Standards to Eliminate Existing Deviations

Our analysis of data requirements and range capabilities clearly showed the need for revised telemetry Standards, in order to adequately serve industry and government. The Telemetry Working Group (TWG) also recognized this need and instructed all members to participate actively in the revision of the Standards. ESD/MITRE contributed to these revisions through their inputs in the form of specific recommendations, which are outlined in the following sub-paragraphs. If implemented, these recommendations will eliminate 60% of the existing deviations, thus reducing customized equipment costs and special handling charges by a similar percentage.

4.1.1 The FM/FM Baseband

The FM/FM baseband is presently defined in the IRIG 106-60 Standards between 370 cps and 80500 cps. The lower and upper limits of this baseband have primarily been dependent upon the frequency response of the most commonly used tape recorders on the ranges such as the FR 100 and the CEC model #5-752. The frequency response for these recorders has been specified by the Standards to be 100 kc. However, specifications show response of 125 kc, and tests conducted at Sandia Corporation verified that a response up to 110 kc is practical. The lower limits of the recorder could be specified to as low as 100 cps. However, no present requirement exists to operate sub-carriers at this low frequency. Based on the recording capability of the ranges, an expansion of the baseband is advisable, since it increases the bandwidth of the FM/FM systems without any economic impact.

It is recommended that the FM/FM baseband be specified as 340 cps to 110 kc.

4.1.2 Additional Subcarrier

The FM/FM system baseband is divided into 18 bands with an upper limit of 80.5 kc. With the extension of this baseband to 110 kc, as recommended above, an additional subcarrier band can be accommodated at 93 kc center frequency. The frequency response of this channel at ± 15% would be 2800 cps and would accommodate many of the existing requirements for higher frequency response at a very low cost to the ranges. This cost would amount to approximately $1000 per FM/FM ground station, namely the cost of a 93 kc discriminator with appropriate band-pass and low-pass filters. Recorders and other equipment on the ranges would be able to accommodate this additional band as previously discussed with very little or no modification.

It is recommended that the list of center frequencies in the current FM/FM Standards include a 93 kc channel @ ± 7.5% and ± 15% deviation with a note specifying that this channel should be omitted when the 100 kc compensation tone in magnetic tape recording is used. This will eliminate 2% of the total deviations.

4.1.3 Percent Deviation of SCO's

The present Standards allow ± 7.5% deviation on all subcarrier bands, and ± 15% deviation on bands 14 through 18 with the restriction that the adjacent band on each side be omitted. The ± 15% deviation could

be extended to some lower bands at the expense of providing a tuning circuit on the appropriate discriminators and adding the required band-pass and low-pass filters. This would allow operation at this greater deviation. The gain would be twice the present frequency response for each of the bands to which this deviation would be applied. This theory can be extended to 22.5% and 30% deviations as well. The gain would be in the form of increased frequency response per band and would be attainable at the low cost of providing a tuning circuit and band-pass and low-pass filters. However, a sacrifice would be evident in the form of a reduction of usable input channels per link. Allowing these increased deviations would provide a more versatile system. Present programs show a definite requirement for the utilization of the FM/FM baseband in this manner. The optimum use of the system is achieved by operating the highest permissable subcarrier oscillator at the greatest allowable percent deviation. A table showing recommended subcarrier frequencies vs. deviations cannot be shown at this time, since, the upper limit of the FM/FM baseband might be extended to 125 kc or 165 kc pending the results of an IRIG/TWG study which will be completed by December 1964. The results of this study will define the limits of the FM/FM baseband to be 93 kc, 124 kc, or 165 kc. However, the general philosophy which might be applied for assigning these deviations can be spelled out in the following recommendation.

It is recommended that the new baseband allow the following percent deviations from the established subcarrier frequencies.

a. ± 7.5% maximum for all SCO's.

b. ± 15% maximum starting with the highest SCO and deleting one adjacent channel on each side.

c. ± 22.5% maximum starting with the highest SCO and deleting two adjacent channels on each side.

d. ± 30% maximum starting with the highest SCO and deleting three adjacent channels on each side.

This will eliminate at least 1% of the total deviations and may eliminate as many as 8% of the total deviations.

4.1.4 PAM/FM/FM Commutation

The PAM/FM/FM table in the Standards has been a subject of criticism for some time now. Certainly, it need be said here that electronic decommutators have been in use for approximately 5 years now, and that most ranges are equipped with one type or another. The flexibility of this equipment is such that it will accept signals from 1 sps to 6000 sps. Channels per frame are available from 5 to 90 and frame rates can be adjusted from .05 to 1000 frames per second. Of all deviations found in our analysis of the PRD's approximately 30% fall into the commutation area. Requirements range from .4 to 3600 samples per second and 3 to 90 channels per frame are used at frame rates as low

as .025 per second, and as high as 100 per second. The numerous deviations listed under commutators indicate that the Standards have not kept pace with requirements and the availability of electronic decommutators at most ranges which accommodate these deviations certainly warrants the following recommendations, without producing an economic impact.

It is recommended that the PAM/FM/FM Commutation Specifications be rewritten permitting sampling rates of one-half the frequency response of the subcarrier channel allowing any combination of samples/frame and frames/second for the specified sampling rate and that this specification be placed in Section 4 with the PAM/FM Standards. The rates specified in Table II should be placed in the appendix and marked for mechanical commutators only. This will eliminate 30% of the total deviations used on commutation rates alone.

4.1.5 RF Carrier Frequencies

We have classified all these deviations as small primarily because approval for use of these frequencies was given by the frequency coordination board in every one of these instances. Deviations were found within allocated telemetry bands, e.g. 227.5 mc, 229.7 mc, 243.6 mc, etc., as well as outside the allocated bands, e.g. 136.020 mc, 150 mc, 400 mc, 959 mc, 5000 mc, 13479 mc, etc. Since approval for use of these frequencies is determined on a non-interferrence basis, these frequencies could be listed

in the Standards with appropriate remarks. No additional equipment is required to accommodate these deviations.

It is recommended that the Frequency Parameters and Design Criteria sections of the RF Standards provide a section that acknowledges the existence of all Geneva Convention Telemetry Bands. However, it should be made clear that the inclusion does not imply sanction or approval by IRIG for unnecessary and arbitrary use of the Geneva Bands. This will eliminate 5% of the total deviations.

4.1.6 IF Bandwidths

IF Bandwidths are specified only in the PAM/FM and PCM/FM sections of the Standards. Thus, deviations in bandwidths below 500 kc found in other systems were marked as deviations. S/N ratio is degraded seriously when RF transmitting bandwidths differ greatly from the receiver IF bandwidth. By specifying the Standard IF bandwidth in use at the ranges in the appropriate sections of the IRIG Standards many of the deviations can be matched closely with very little degradation in S/N. Systems using narrow bandwidths should consider transmitter and receiver stabilities, and many require matched components or automatic frequency control. (i.e., the FM/FM transmitter and receiver stabilities as specified in the Standards allow frequency drifts up to 30 kc.).

It is recommended that all sections of the IRIG Standards list the same IF bandwidths as shown in the PAM/FM/FM and PCM/FM sections, with appropriate limitations such as transmitter and receiver instabilities. This will eliminate 20% of the total deviations.

4.2 Recommendations for Revision of the 106-60 Telemetry Standards to Forestall Future Deviations

The context of this section points out areas of the Standards where a forward look is required in order to provide industry and Government with a guide for their present and future requirements. Unless the IRIG/TWG seriously considers the incorporation of these suggestions, the Standards will not be the leading document that it was intended to be. A firm direction has to evolve from these Standards which provides a look into the future, and anticipates requirements in order to provide a well organized evolution of future telemetry systems.

4.2.1 Design and Use Criteria

The present Standards give very little information to the design engineer who is faced with a requirement problem that cannot be met by any of the present Standard systems. Since the limits of these systems are defined by precise boundaries, without an explanation as to how one arrives at these limits, the user or designer has no knowledge of the true capabilities of the systems and the trade-offs it might offer, should

he exceed the limits. In many instances his requirements could still be met by stretching the capabilities of the system, without the need for specialized equipment. Typical examples would be the frequency response that can be gained by lowering the deviation ratio in FM/FM systems, or the additional use of adjacent subcarriers that might be used if the frequency response of the data does not violate the established guard bandwidth. Since none of this type of information is available in the Standards, the user is forced to believe that existing Standard systems cannot meet his requirements and he, therefore, seeks refuge in some newly proposed, non-Standard systems. The detailed design and system limits, showing trade-offs in S/N, increased error rates and many other parameters should therefore be added to the Standards.

It is recommended that a design and use criteria section be added to the appendix of the IRIG 106-60, consisting of documents and papers which would aid the design engineer in the selection of system parameters other than the ones clearly defined in the content; e.g., frequency response vs S/N ratio at modulation indexes lower than 5.

4.2.2 Design and Use Criteria for the FM/FM System

The FM/FM subcarrier oscillator table provided in the Standards shows frequency responses based on a modulation index of 5. The data

accuracy which might be expected if related to % error would be about 1%. A decrease in modulation index down to 1 will decrease this accuracy to about 5%. This information is not stipulated in the Standards. Since most requirements for programs using FM/FM systems do not expect to get a greater accuracy than 5% it would be much more appropriate to change this table to one based on a modulation index of 1, thus increasing the data handling capability of this system by a factor of 5, without major procurement requirements, since available low pass filters can be matched with the increased frequency response of the individual subcarriers, with the exception of some upper channels.

It is recommended that paragraph 2.2.1 of the Standards be supplemented in the design and use criteria section by specifying frequency response vs. percent increase in noise for modulation indexes down to 1, and a listing of available low-pass filters which may be used with these frequencies.

4.2.3 PCM Bit Rate and IF Bandwidth

The PCM section of the Standards shows a table, relating sampling rates to available IF bandwidth. The table is organized in a manner which does not clearly define where the capability of each IF Bandwidth ends with regard to an upper limit of bits/second. It should therefore be revised showing the range of bits/seconds that may be accommodated by each IF bandwidth.

It is recommended that Table I, PCM bit rate and receiver IF bandwidth be revised to specify the bit rate capability for each single bandwidth, i.e., 8000 bps to 16000 bps for receiver IF bandwidth of 25 kc, 16000 bps to 33000 bps for IF bandwidth of 50 kc etc.

4.2.4 RF Standards for UHF

The parameters given in Appendix I of the Standards, as regards the UHF section are not clear and require more specific information in some paragraphs. Although the UHF band is defined by specifying the maximum and minimum frequencies, it has not been brought out that the end points of the spectrum are 1435.5 to 1534.5 and 2200.5 to 2299.5. The bandwidth section as well as the section on channel spacing clearly stipulates a 1 mc bandwidth between RF links. However, section 2.2.3.2 also stipulated the use of $\pm$ 125 kc deviation for this bandwidth. It seems unreasonable that the deviation for the UHF band should be stated at 1/8 of the available bandwidth, while the VHF band allows a deviation of 1/4 of the available bandwidth, spurious and harmonic minimum requirements being the same for either band.

It is recommended that the RF Standards for the UHF bands specify the end point frequencies of 1435.5 to 1534.5 and 2200.5 to 2299.5 as well as the 1 mc channel spacing and quote $\pm$ 250 kc maximum RF deviation with the maximum modulation bandwidth of 1 mc.

.2.5 FM/FM Subcarrier Bands

Section 2.2 of the Standards stipulates that a list of Standard subcarrier band center frequencies are available. A statement like this leads one to believe that a choice is offered between the use of these subcarriers, or some other convenient arrangement, which may more readily fit the individuals needs. This however is not the case nor the intent. Therefore a more restrictive statement should be made in this section. Furthermore, the statement that test ranges are capable of supporting at least 12 of these subcarriers simultaneously is no longer valid, since capabilities of the ranges have greatly increased over the past years.

It is recommended that a stronger statement be made in paragraph 2.2, "Subcarrier Bands", regarding the use of the specified subcarrier frequencies; such as: Subcarrier frequencies shall be selected from those specified in Table I. Also, the statement that ranges be capable of simultaneously handling a minimum of any 12 of these subcarrier signals should be modified to reflect the present greater capability of the ranges.

4.2.6 FM/FM Subcarrier Oscillator Table

The subcarrier table in the FM/FM section of the Standards shows a larger gap between band 13 and band 14 than is provided between other bands. The reason for this is not apparent without reading paragraph 2.2.2 which gives an explanation for this deviation. In order to more readily

identify the reason for this deviation a note should be inserted in the table bringing the readers attention to this fact.

It is recommended that a note be inserted between band 13 and band 14 of the list of center frequencies in the current FM/FM Standards, indicating that the larger gap between these bands was left to provide for the 17 kc $\pm$ 60 cycles compensation tone in magnetic tape recording.

4.2.7 FM/FM Subcarrier Oscillators and PAM Commutation

The PAM/FM/FM table allows subcarrier oscillator use down to band 13. It appears obvious that the table was stopped at an arbitrarilly selected point, since no technical reason could be found for not allowing commutation on lower SCO's. Should the need arise to make use of the lower bands for commutation purposes, the present Standards would not provide for this need. On the other hand no technical or economical impacts are expected by allowing this greater flexibility.

It is recommended that Table II, IRIG 106-60 be supplemented, allowing PAM/FM/FM commutation below the lowest recommended subcarrier band.

4.2.8 PCM/FM/FM

The present Standards allow only for a PAM and PDM pulsing of the FM/FM system. The system however would lend itself very well to other types of pulsing if the requirement exists. An example might be the need

to monitor some guidance and control computer outputs, which normally are in digital form. Acceptable bit rates about 4 times the PAM commutation rates are technically feasible and would provide sufficient information for some of the required uses.

It is recommended that use of PCM/FM/FM be allowed in the FM/FM Standards at bit rates 4 times the PAM commutation rates.

4.2.9 Frequency Parameters for Transmitters and Receivers:

Section I of the Standards is devoted to Radio Frequencies. The section consists of a single paragraph which refers the reader to the appendix of the document for detailed information. It is felt that this information which deals with the use of the RF spectrum rightfully belongs at the beginning of the Standards as a whole.

It is recommended that Appendix I be transferred to section I of the IRIG 106-60.

4.2.10 Mistakes in the Standards

Two mistakes were found in the review of the Standards which should be corrected as follows:

It is recommended that Table IV be corrected. Reference is made to "Appendix II", which should be changed to read "Appendix IV".

It is recommended that Figure 2 be corrected. The minimum signal should follow immediately after the frame sync. pulse, and the maximum signal should follow immediately after the minimum signal.

4.3 RECOMMENDATIONS FOR FUTURE STUDIES

As a result of the investigations conducted under the ESD/MITRE Telemetry Standardization Program several specific areas have been identified which require analysis, test, and evaluation. Some of these studies will result in up-dating of current techniques and equipment, others will recommend preferred designs, advanced formats, and standards. Significant studies to be pursued by this program during FY-65 are outlined below.

4.3.1 Studies to Up-Date the Standards

The recommended changes to the Standards will be reviewed and analyzed to form the basis for up-dating the Standards. Design and use criteria will accompany the proposed revisions to provide guidance for the use of these added capabilities. This design and use criteria is intended for inclusion in the Appendix of the Standards. The changes will be implemented through ESD membership in the Telemetry Working Groups, the Frequency Multiplex Systems Committee, and the Time Multiplex Systems Committee. Studies in progress are expected to result in the incorporation of the following:

a. Lowering of the modulation index

b. Increase the number of bits/frame

c. Increase PDM commutation rates to take full advantage of the bandwidth capabilities.

d. Increase PDM samples/frame and frames/sec.

4.3.2 Studies on Current and Advanced Systems and Techniques Requiring Immediate Consideration

The following studies are limited in scope but are expected to improve and expand present systems and range equipment, consistent with the most economic improvements and additions.

a. Analysis and Recommendation on Use of Tape Speed Error Correction Channels (17 kc, 100 kc or other) in Relation to Inclusion of a 93 kc Channel in the Normal FM/FM Baseband.

This also includes an independent verification of the FR 100 frequency response limits for FM/FM recording and reproducing, and to a limited extent, an investigation of the present status of range recording particularly as regards predetection recording.

b. Approximate Evaluation of Frequency Modulation Errors Due to Low Deviation Ratios (less than 5) and/or High Percent Deviations (greater than 7.5%).

This will be limited to obtaining a first-order answer for guidance in present usage of, and adjacent channel interference in, the FM/FM system, and for guidance in the basic Frequency-Division Studies.

c. Economic and Technical Evaluation of (Constant Bandwidth) Use of an Additional FM/FM Baseband.

This will be limited to use of any additional baseband by conventional frequency-division methods (e.g., DSB, FM or AM subcarriers). The constant-bandwidth division of this additional baseband will be emphasized.

d. Theoretical and Practical Evaluation of Pulse Operated Frequency Division System Channels.

The objective is to establish a first-order relation between subcarrier channel bandwidth, deviation ratio, and permissible maximum pulse rate for given data accuracies and S/N conditions, in particular for the FM/FM format and its use on PAM, PCM and PDM data.

e. Investigation of PDM and PPM Techniques

This involves a short critical survey of analog data systems using pulse time as the variable. The objective is guidance for recommending either future use, continued use, or elimination from use.

f. Evaluation of Frequency Division Systems Channel Allocation and Operation by a Steady State Analysis Method

This is a relatively simple, but basic, analytical method that can provide very clear design and use criteria for frequency-division systems. The results will be directed to a critical survey of the present FM/FM system, and also to the allocation and use of RF channels.

g. Evaluation of Frequency Division Systems Operation by an Approximate Dynamic State Analysis Method

This method gives a closed form solution which does not require computer time. The results will be a first order estimate of adjacent channel interference which will be considered with the evaluation in f. above. The method has been used, but not in sufficient depth, in the design and use of commutated FM/FM telemetry systems using the standard IRIG Channels.

h. General Analysis of Transducer Responses, Required Sampling Rates, and Inherent Data Degradation in Pulse Systems

Groups of transducers having similar rolloff rates, required sampling rates for given aliasing errors, and the general degradation

due to using sampling as opposed to continuous (frequency division) methods will be established. Recommendations on improving the transducer rolloff rates will be made. This work is basic to any future comparisons (both economic and performance) between pulse and analog telemetry systems.

i. Practical Analysis of Noise Errors Due to "Sampling and Hold" Techniques

A working estimate is required of the practical errors due to amplitude and time jitter of conventional sample and hold techniques as used in Time-Division (PAM, PDM, PCM) Systems.

j. First-Order Evaluation of Effects of Phase Non-Linearity

Phase non-linearity is receiving belated attention, and it is desired to establish the effects at points in a telemeter where such occurs; for example, at all points where reactive elements are vital, such as bandpass and lowpass filters, voltage controlled oscillators, etc. Only first-order effects and their relations to overall data reproduction inaccuracies are desired, for guidance in validating longer-term practical work.

k. Ground/Airborne PCM Capability and Current PCM Techniques

This is a review of PCM telemetry state-of-the-art, including techniques and equipment available. Particular attention is to be paid to peripheral equipment, to the necessity for "house-keeping" bits per word in addition to the data bits, and to the trade-off between the large increase in channel bandwidth required versus the reliability, accuracy and convenience of the PCM method.

Recommendations should be made as to preferred processes insofar as they are distinguishable independently of the overall data transmission techniques.

q. PAM/FM (PAM/FM/FM) and PACM Integration

The ESD/MITRE Recommendations, as applied to the revised Standards, stipulate a maximum pulse rate of 1/3 the channel bandwidth, for PAM operation. This criteria may now be used in this task, to stipulate a relation between PAM and PCM pulse lengths which can form the basis for a PACM system standard.

4.3.3 Basic Studies Leading Toward Standard Telemetry Systems

All Standard and presently-used non-Standard telemetry modulation formats and systems will be categorized into three basic classes of systems.

Frequency-Division Systems (FD)
Time-Division Analog Systems (TDA)
Time-Division Coded Systems (TDC)

Typical system formats as outlined in this report and found elsewhere will be oriented as follows:

FD	TDA	TDC
FM/FM	PAM/FM/FM	PCM/FM
FM/FM/FM	PAM/FM/PM	PCM/FM/FM
PM/FM	PAM/FM/AM	PCM/PS/AM

FD	TDA	TDC
FM/AM	PAM/FM	PCM/FM/PM
SS/FM	PAM/AM	PCM/PS/FM
AM/FM	PPM/AM	PCM/PM/PM
DSB/FM	PDM/FM	Digilock (Tanlock)
Orthomux	PDM/PM	Duobinary
Orthomatch	PFM/FM	
	PFM/AM	
	PACM/FM	

These systems will further be organized as to similarities and performance and these groups will be studied under the above defined basic classes. The PAM/FM/FM - PAM/FM/PM and PAM/FM/AM modulation formats would be representative of such a group. The respective technical and economic advantages and trade-offs will be determined through systems evaluation, and tests on critical systems and subsystems will be investigated and analyzed. A final determination will be made to delete redundant and unnecessary modulation formats of the selected groups, and to propose a standard modularized telemetry station, capable of handling all essential formats. Studies will be pursued to produce the following outputs:

a. System evaluation and test reports.

b. Preferred design, performance and use criteria for selected systems.

c. Modulation/demodulation methods for optimum use of data bandwidth.

d. Channel selection methods based on minimum interference for available bandwidth, and optimum use of the spectrum.

e. Adaptive data selection methods for minimizing equipment.

f. Preferred modulation formats.

g. Advanced systems requirements.

h. Recommended standard telemetry systems.

i. Advanced standards.

4.4 Recommendations to USAF and Other Users

During our investigation of specific DOD programs, it became apparent in a number of instances, that several deviations from the standards were without apparent reason or necessity. The consequences became apparent only after non-standard range equipment was requested by the program offices through the initiation of PRD's. Since there was no coordination between the specific projects, deviations chosen for similar requirements differed from program to program. This can well be illustrated in the case of additional SCO use in the FM/FM system. Numbers were chosen arbitrarily such as 85.0 kc, 93.0 kc, 100.0 kc, etc. At the range, discriminators had to be provided for each of these frequencies. One selected frequency such as 93.0 kc based on the logical proportional extension of the baseband could have served all, and avoided the need for wasteful procurement at the ranges to handle several deviations for the same requirements.

4.4.1 Focal Point for Coordination

Primary consideration should be given to the establishment of a focal point. In the past many of the redundant deviations can be attributed to the lack of a centralized organization charged with the coordination and control of deviations. It is recognized that not all requirements can be met by standardized equipment; however, redundant deviations to the standards can and should be minimized.

It is recommended that a focal point be established for analysis, coordination and control of all DOD program telemetry deviations.

4.4.2 Mandatory Adherence to Standards

The success of standardization depends largely on enforcement. Reduction in cost can only be achieved after DOD directs program offices to adhere to the Standards to the maximum practicable extent and that adequate justification be given to the organization established as focal point for all deviations.

It is therefore recommended that DOD issue a directive for mandatory adherence to the telemetry standards and for submittal of Requests for Approval of all deviations to the designed focal point recommended in 4.4.1.

4.4.3 Specific Program Oriented Recommendations

Since some of the deviations from the Standards were found to be unnecessary, ESD will propose specific changes that can be made to AF programs to eliminate these deviations. It is recognized that these

changes cannot be implemented immediately but need to be interlinked with existing program schedules. Changes could best be accomplished at a time when other modifications to the system are essential. It is suggested that other DOD agencies also follow this procedure to bring their programs in line with the revised Standards.

Specific program oriented recommendations will be forwarded to AFSC.

5.0 CONCLUSIONS

This report outlines in detail non-Standard telemetry data requirements for all available DOD programs. The data presented constitutes one of the largest collections of non-Standard telemetry data presently in existence. A detailed analysis of the data requirements is published as ESD-TDR-64-155, entitled "A Study of Non-Standard Telemetry System Characteristics". This detailed analysis and the recommendations made in section 4 of this report show a trend for future DOD requirements in aerospace telemetry which lead to the following conclusions:

5.1 Present IRIG 106-60 Standards Require Up-Dating

The recommendations in section 4 calling for up-dating the Standards were made after careful consideration of the non-Standard telemetry systems characteristics and a thorough study of the existing IRIG 106-60 Standards.

5.2 Detailed Study Efforts on Existing Standard Systems are Required

The recommendations in section 4 outline the areas for future investigation and development, for better utilization of present techniques and more efficient operation of existing standard systems.

5.3 Proposed New Telemetry Systems and Techniques Need to be Classified and Analyzed

The recommendations in section 4 further establish procedures which will be followed by the ESD Telemetry Standardization Program to classify all proposed modulation techniques, to eliminate similar techniques, and to show economic and technical trade-offs for new techniques.

5.4 A Minimum Number of Techniques Should Be Standardized

Finally, a selected number of techniques to handle the majority of all DOD telemetry requirements will be recommended as standards; others will be noted for their special purpose applications.

5.5 A Standard Modularized Telemetry Station Should Be Considered

The end product of this program should contribute to concepts for a standardized, modularized telemetry ground station capable of handling all standard modulation formats. Provision should also be made for acceptance of special purpose elements to handle unique needs at a minimum expense to the DOD. Preliminary work leading to formulation of a development plan for such a station is presently underway at ESD.

5.6 Mandatory Adherence to Standards is Essential

The success of standardization depends largely on enforcement. A DOD directive is required for mandatory adherence to Standards to the maximum practical extent.

REFERENCE BIBLIOGRAPHY

1. Telemetry Standards, IRIG Doc #106-60 (Rev 1 Jun 62) Inter-Range Instrumentation Group of the Range Commanders Conference

2. A Study of Non-Standard Telemetry System Characteristics ESD-TDR-65-155, Headquarters ESD, L. G. Hanscom Field, Bedford, Mass, 31 August 1964

3. Implementation Plan for Telemetry Systems Standardization, Headquarters ESD, Directorate of Aerospace Instrumentation, L. G. Hanscom Field, Bedford, Massachusetts, June 1963.

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13. ABSTRACT

Summarized in this report are the findingsof a program entitled "Telemetry Systems Standardization". The primary objective of the program is to standardize on a minimum number of telemetry systems which will meet present and future Air Force requirements. This report represents the initial step toward this goal by providing an insight into the usage of present telemetry systems through the categorization of the characteristics of telemetry systems. Included also is a summarization of the recommendations and suggested studies arising out of a thorough evaluation of the data and IRIG Telemetry Standards reported separately in ESD-TDR-64-155, "A Study of Non-Standard Telemetry System Characteristics."

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